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# Super insulation materials in the building sector: Field studies and future challenges

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**ABSTRACT**
The global rate of improvement in energy efficiency have to be increased to reach the UN sustainable development goals by 2030. Super insulation materials (SIM) can maintain the same thermal transmittance with a thinner insulation layer compared to conventional insulation materials. Recommendations and experiences from practical applications are needed to raise the knowledge and awareness of using SIM in buildings. Evidences related to real-condition performance need to be presented and independently assessed. The aim of this paper is to describe the state-of-the-art in the area of SIM in building applications based on monitoring data related to long-term performance of vacuum insulation panels (VIP). Both VIP and advanced porous materials (APM) have been successfully installed over the past 15 years in buildings. This paper presents a case study where the temperature and relative humidity of a wall were monitored for seven years. The results of the monitoring indicate that the VIP fulfil its function with no sign of degradation. By continuous product development, the performance of the SIM are improved for every generation which gives a promising outlook for the wider implementation of SIM in the building envelope.

**KEYWORDS**
Super insulation material, aerogel, VIP, renovation, energy efficiency, building

## INTRODUCTION

There is presently a focus in the European Union to decrease the carbon dioxide emissions from the built environment. On the global arena, the UN sustainable development goals put focus on integrating climate change measures. By 2030 the global rate of improvement in energy efficiency should be doubled. This requires new and more energy efficient materials to be developed and evaluated. Conventional insulation materials require a certain thickness to reach a sufficient thermal transmittance. Super insulation materials (SIM) can maintain the same thermal transmittance with a thinner insulation layer. Products are available on the market which offer down to one tenth of the thickness required for conventional insulation materials. This is especially interesting in retrofit applications and in areas with limited land accessibility.

In many of the field studies reported in the literature only the thermal performance of the assembly was investigated (Johansson, 2012). However, also other parameters, such as the moisture performance, is important to consider. Recommendations and experiences from practical applications are needed to raise the knowledge and awareness of using SIM in buildings. Evidence related to real-condition performance needs to be presented and independently assessed. Full scale experiments provide knowledge of practical and technical difficulties as well as data for service life estimation. For certain conclusions to be drawn from case studies, long-term monitoring is needed. Unfortunately, monitoring is only performed in few case studies reported in the literature.

One of the International Energy Agency's (IEA) Energy in Buildings and Communities (EBC) Programme's objective is to enable research and development programmes (Annex) on the building envelope among its 24 member countries. During 2014 the Annex 65 'Long Term Performance of Super-Insulating Materials in Building Components and Systems' was initiated. The work was divided in 4 tasks where task 3 concerned field scale performance of SIMs. The focus of the work was to define the application areas of SIMs and to describe the conditions of the intended use of the products having building retrofit in mind (Adl-Zarrabi & Johansson, 2018).

The aim of this paper is to build on the conclusions of the Annex based on monitoring data related to real-life performance of VIP in buildings. By presenting the state-of-the-art in SIM applications in buildings and a case study with 7 years of monitoring data of a VIP wall installation, future research directions and recommendations for further actions are presented in the area of SIM in building applications.

**SUPER INSULATION MATERIALS**

Conventional insulation materials use entrapped air as insulator inside a porous matter. Examples of these are mineral wool, expanded polystyrene and polyurethane. By using different additives, the thermal conductivity can be reduced by targeting the three main heat transfer mechanisms presented in Figure 1 (Berge & Johansson, 2012).

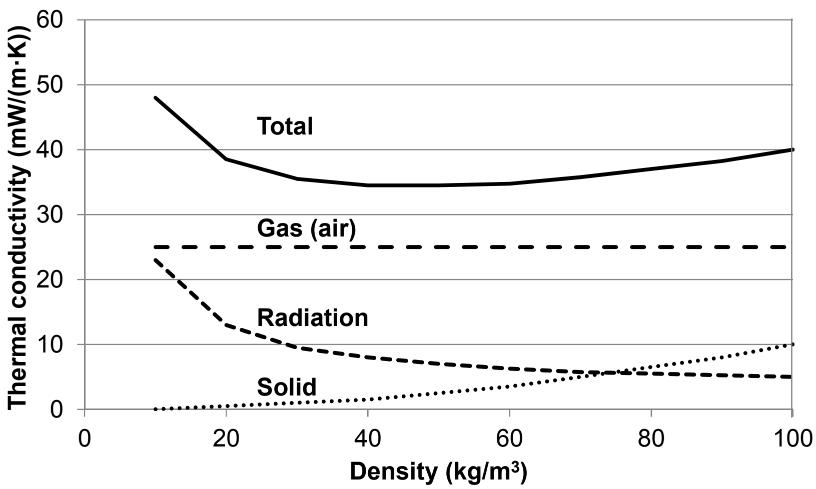



Figure 1. Thermal conductivity in porous materials divided into the three main heat transfer mechanisms (adapted from (Simmler et al., 2005)).

The total thermal conduction can be reduced down to a minimum around 30 mW/(m·K), which can be compared to stagnant air which has 25 mW/(m·K). Therefore, in this paper SIMs are defined as materials having a thermal conductivity lower than stagnant air ($\lambda$ = 25 mW/(m·K)) To reduce the thermal conductivity further, the heat transfer through the gas has to be reduced. This can be achieved by a) hindering the gas movements in the pores by reducing the pore size, b) removing the gas, or c) a combination of both a) and b) (Berge & Johansson, 2012).

In the context of Annex 65, SIM were divided in advanced porous materials (APM) and vacuum insulation panels (VIP). APM are materials where the heat transfer through the gas is hindered significantly by the fine pore structure. These can further be divided in two groups, porous silica, e.g. based on fumed silica, and aerogels. APM have been installed since the early 2000s in buildings (case studies) and assemblies. The products available on the market are more similar to conventional insulation materials in most aspects. However, knowledge related to behavior of AMP are needed for performance prediction at the material, component and building scale. The aerogel based products, such as blankets, are in general vapor permeable and hydrophobic.

The second group of products is VIP. Here the contribution of heat transfer through the gas is suppressed by evacuation. These can be further divided in different core materials (fumed silica, glass fiber, polyurethane, expanded polystyrene and others), different envelopes (metalized film, aluminums laminate, stainless steel, glass, or combinations), and with or without a getter and/or a desiccant. Since VIP have less similarities to conventional insulation materials these products will be the focus of this paper.

Generally there are a number of challenges remaining when using VIP in buildings. The first challenge is the cost versus performance ratio. The thermal performance of VIP is practically 5 times better than conventional materials while the price is generally around 10 times higher. There are applications where the high performance and cost can be reasonable. The second challenge is the long-term performance of VIP. The service life of a building is 25-100 years while the VIP for building applications have been developed in the recent decades. The third challenge is that the construction market is a conservative market, regulated by numerous codes and standards, and thus, introducing new products takes a long time. The fourth challenge is knowledge and awareness among designers concerning using VIP. To provide answers to these challenges, field studies can provide insight on how the materials perform during normal use conditions (Adl-Zarrabi & Johansson, 2018).

During the years several research projects have focused on evaluating VIP in the field. The possibilities to use VIP in buildings was investigated during 2002-2005 by Binz et al. (2005). They studied in total 20 constructions with focus on the energy use, thermal bridges and moisture performance. In a study Heinemann and Kastner (2010) used infrared thermography to investigate the performance of the VIP after some years of use in the buildings. They concluded that as long as the VIP is not damaged at installation, about 95% of the VIP will maintain the vacuum several years. One of the most predominant building elements where VIP have been used is in flat roofs. At Empa in Switzerland researchers have monitored a roof construction containing VIP since 2004. Brunner and Ghazi Wakili (2014) measured the thermal conductivity of the VIP which had increased to 6.6-7.0 mW/(m·K) after 9 years. This is an increase of 65-75% from the initial thermal conductivity of 4 mW/(m·K). However, it is still well below the thermal conductivity of conventional insulation materials and the thermal conductivity of the core material at atmospheric conditions, 20 mW/(m·K).

## CASE STUDIES USING VIP

Full scale experiments provide knowledge of practical and technical difficulties as well as data for service life estimations. For certain conclusions to be drawn from existing case studies, long-term monitoring is essential. Unfortunately, monitoring is only performed in few case studies. In total 22 case studies using VIPs, spread over 10 countries on 3 continents, were collected within Annex 65. The design process, practical aspects and results were described for each of these case studies. Of the 22 case studies only 4 were monitored and of these 2 were laboratory setups and 2 were field test of an external wall. The installation of the VIPs is the critical process which calls for inspection of the VIPs at the construction site before installing them. Considering the large amount of installed VIPs in case studies reported in Annex 65 in different countries (Figure 2) it is a pity that not more cases have been followed up.

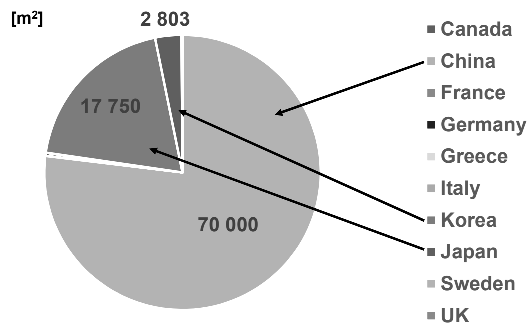
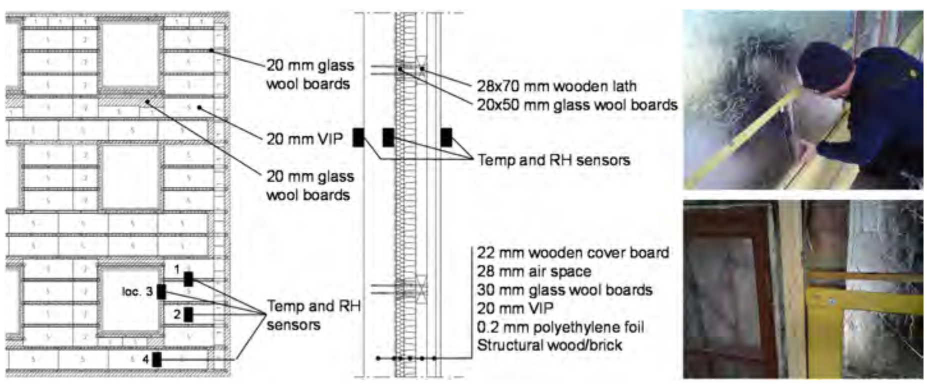



Figure 2. Installed VIP ($m^2$) in case studies in Annex 65 (Adl-Zarrabi & Johansson, 2018).

In an ongoing study in Gothenburg, Sweden, a renovated building was monitored for 7 years with data presented for each year. The case study building was a listed building from 1930 which was insulated on the exterior with 20 mm VIPs. The calculated energy use for heating decreased by 24% (Johansson et al., 2014). Temperature and relative humidity sensors were installed in the test wall and in a neighboring (non-retrofitted) wall as reference, see Figure 3.




a) b) c)

Figure 3. a) wall layout after retrofitting with 20 mm VIP and 30 mm glass wool boards, b) section of the wall layout with the location of the temperature and RH sensors in the wall marked by the black boxes (not in scale), c) installation of the VIP layer with the glass wool boards creating a thermal bridge between the VIP themselves and between the VIP and windows.

The hygrothermal performance was monitored by sensors integrated in the construction. The monitoring results for first 5 years were presented in (Johansson et al., 2016). The temperature and RH in the wall was recorded during 5 years, from January, 2011, to December, 2015. The measurements showed no sign of deterioration of the VIP and there was a low risk for condensation in the construction. It was concluded that the hygrothermal performance of the test wall was substantially better than that of the reference wall (Johansson et al., 2016).

The external air space made it impossible to identify the different panels by thermography. Only indirect methods, like evaluation of the measured temperatures in the wall, could be used to follow the long-term performance of the panels. For this analysis the average temperature for January each year 2011 to 2017 was used to calculate the temperature factor, see Figure 4. Unfortunately several sensors have been damaged why only one position can be evaluated for all 7 years.

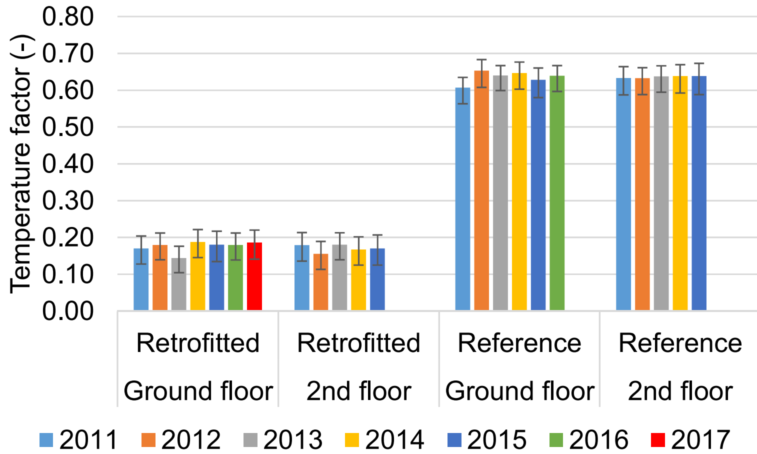



Figure 4. The temperature factor of January 2011 to 2017 for the retrofitted and reference walls. The temperature factor is the percentage temperature decrease over the original wall compared to the total temperature drop over the wall. The error bars show an accuracy of the sensor of ±0.5°C (adapted from (Johansson et al., 2016)).

In the reference wall about 64% of the temperature drop was over the uninsulated parts. After the retrofitting only about 17-18% of the temperature drop was over that part of the wall. The results indicates that after 7 years there was no sign of decreased insulation performance of the VIP. The results of this case study after 7 years is in good agreement with also the conclusion from several case studies that were collected in Annex 65 (Adl-Zarrabi & Johansson, 2018).

## CONCLUSIONS

During the work of the Annex 65 several questions regarding the long-term performance of VIP and their application on the building scale were identified and discussed. Based on the experiences in the case studies, it was possible to identify application areas and the conditions of the intended use of VIP. It is clear that special care is necessary during installation compared to conventional insulation materials, since the VIP are sensitive to mechanical puncturing of the envelope. Therefore, there may be a need for certification of craftsmen and need of special training.

The building industry is generally conservative to new solutions and materials. The industry is regulated by numerous codes and standards, and thus, introducing new material takes a long time. Results obtained by activities in Annex 65 can be used for convincing the building industry about the performance of SIMs.

The ongoing standardization on the material and product levels may trigger building components with VIP to be introduced on the market. There are valuable savings of space when less area is needed for the building elements which leads to an increased rental income. There can also be technical reasons to select a VIP, i.e. when conventional insulation materials are not a practical alternative or for architectural reasons.

The theoretical investigations and first practical tests showed that VIP, especially those with fumed silica core, are expected to fulfil the requirements on durability in building applications for more than 50 years. Both VIP and APM have been successfully installed over the past 15 years in buildings. However, real experience from practical applications exceeding 15 years for VIPs is still lacking.

The long-term performance (25-100 years) cannot be entirely determined due to lack of data for longer time period exceeding 15 years. However, as seen above and more thoroughly discussed in the report of Annex 65, there were few claims concerning the malfunction of SIM in construction. The products are in continuous development and the VIP that were installed several years ago are no longer available on the market. By continuous product development the performance of the products are improved for every generation which gives a promising outlook for the wider implementation of SIM in the building envelope.

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